SECTION 2
Water Quality Monitoring Programs

King County has conducted an extensive marine monitoring program for almost 40 years to assess water quality in Puget Sound. The monitoring program contains elements of baseline sampling to assess background conditions (ambient monitoring) and also sampling to assess conditions around King County's marine outfalls (point source monitoring).

The goal of the marine monitoring program is to identify sources of water pollution, provide water quality information for management decisions, and evaluate status and trends of marine waters within King County.

In order to meet that goal, the marine monitoring program works within a framework of the following objectives:

- implement a long-term monitoring program to characterize water quality in King County;
- evaluate data results in regard to applicable State water and sediment quality guidelines;
- comply with NPDES sediment monitoring requirements;
- gather sufficient data to determine both short and long-term water quality conditions;
- determine physical and chemical dynamics that influence water quality;
- support coordinated regional monitoring efforts; and
- collect scientific data of high quality to inform water quality management decisions.

Water quality may be affected by natural processes as well as by two types of pollution: point source and nonpoint source. Point source pollution is defined by its entry into the aquatic environment from a specific conveyance, such as an outfall pipe. Point source pollution can be generated by a variety of industrial and municipal facilities, such as sewage treatment plants and manufacturing facilities. Nonpoint source pollution comes from any source that is not a point source and includes runoff or infiltration from streams, groundwater, stormwater, atmospheric deposition, etc. Land use, such as agricultural and urban usage, affects the quality of the runoff. King County's marine monitoring program assesses both nonpoint and point source pollution in nearshore and offshore environments, as well as assessing ambient (background) conditions. The stations monitored by the marine program fall into one of two categories; ambient or outfall (point source). Within these categories, stations are classified as either beach (+3 to -3 meter mean lower low water) or offshore (bottom depth greater than -3 m mean lower low water).

Obtaining background data from areas in receiving waters that are not influenced by point sources is important in order to accurately evaluate the overall condition of receiving waters. King County has established an ambient monitoring program in the Central Puget Sound Basin to better understand regional water quality and provide data needed to identify trends that might indicate impacts from long-term cumulative pollution.

2.1 Outfall and Ambient Monitoring Programs

The outfall and ambient monitoring programs focus on both marine water and the underlying sediments. Many marine pollutants are associated with particulates in the water. As these contaminated particles settle out of the water column, pollutant concentrations in the underlying sediments tend to increase. Most pollutant sources are found in shallow nearshore areas where pollutants tend to accumulate in sediments close to these sources. Benthic organisms that live on or in contaminated sediments tend to accumulate these contaminants through contact or ingestion (bioaccumulation). Pollutants also tend to concentrate as they move from one trophic level to the next (biomagnification), as contaminated organisms become prey to animals higher up in the food web. Contaminated sediments can have an impact on both human and marine environmental health, especially in nearshore areas which are generally high contact areas for marine organisms and people.

Water monitoring for physical, chemical, and biological parameters is an important component of the County's monitoring programs. In offshore and beach waters, excess nutrients and pathogens can cause water quality related problems for both animals and humans. While excess nutrients do not cause immediate harm to organisms living in the water column, they can increase the growth of phytoplankton and algae. The decay of phytoplankton and algae populations can subsequently deplete oxygen to levels incapable of sustaining aquatic organisms. Physical parameters, such as salinity and temperature, are important as these properties affect water column stratification. The intensity and persistence of density stratification within a water column is significant with respect to vertical water movement, phytoplankton growth, and dissolved oxygen concentrations.

2.1.1 Marine Outfall Monitoring Program

King County collected offshore water column samples at wastewater and CSO treatment plant outfall discharge locations in 2005, 2006, and 2007 as part of the outfall monitoring program. Beach water and shellfish tissue were also collected from areas in the vicinity of treatment plant outfalls during all three years. Macroalgae tissues were collected from areas in the vicinity of treatment plant outfalls in 2005, however, the macroalgae sampling program was discontinued in 2006. Beach sediments were collected in 2005 but not 2006 or 2007. Beginning in 2005, beach sediments in the vicinity of outfall sites and at ambient sites are collected on a five-year cycle. Water samples were collected from multiple depths at the offshore stations and from a single depth at the beach stations. Offshore sediments at the West Point TP outfall were collected in 2006 in support of the NPDES permit. Station locations are shown in Figures 2-1 through 2-3 and station coordinates are provided in Appendix E.

Outfall stations that were sampled between 2005 and 2007 were also sampled in previous years with the following exceptions described below. In 2006 and 2007, a station was sampled at the mid-diffuser point for each of the South TP twin outfall pipes in an effort to determine if there were discernible water quality differences between the two locations. A beach site in the vicinity of the Alki CSO TP outfall was added in 2006, however, this site was subsequently removed from the sampling program in 2007 as it was deemed to be unrepresentative of the outfall area.

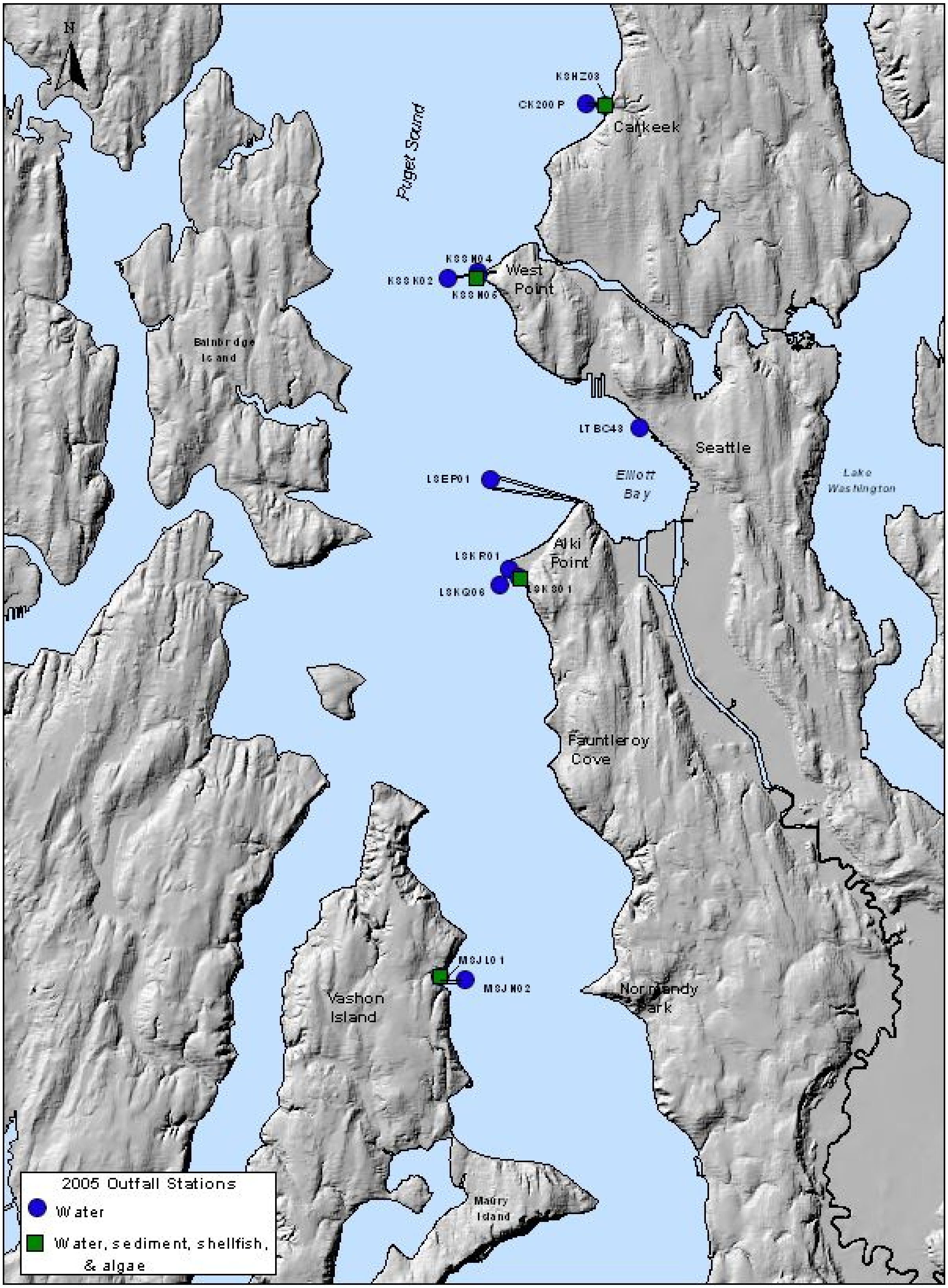

Figure 2-1. 2005 Outfall Monitoring Station Locations

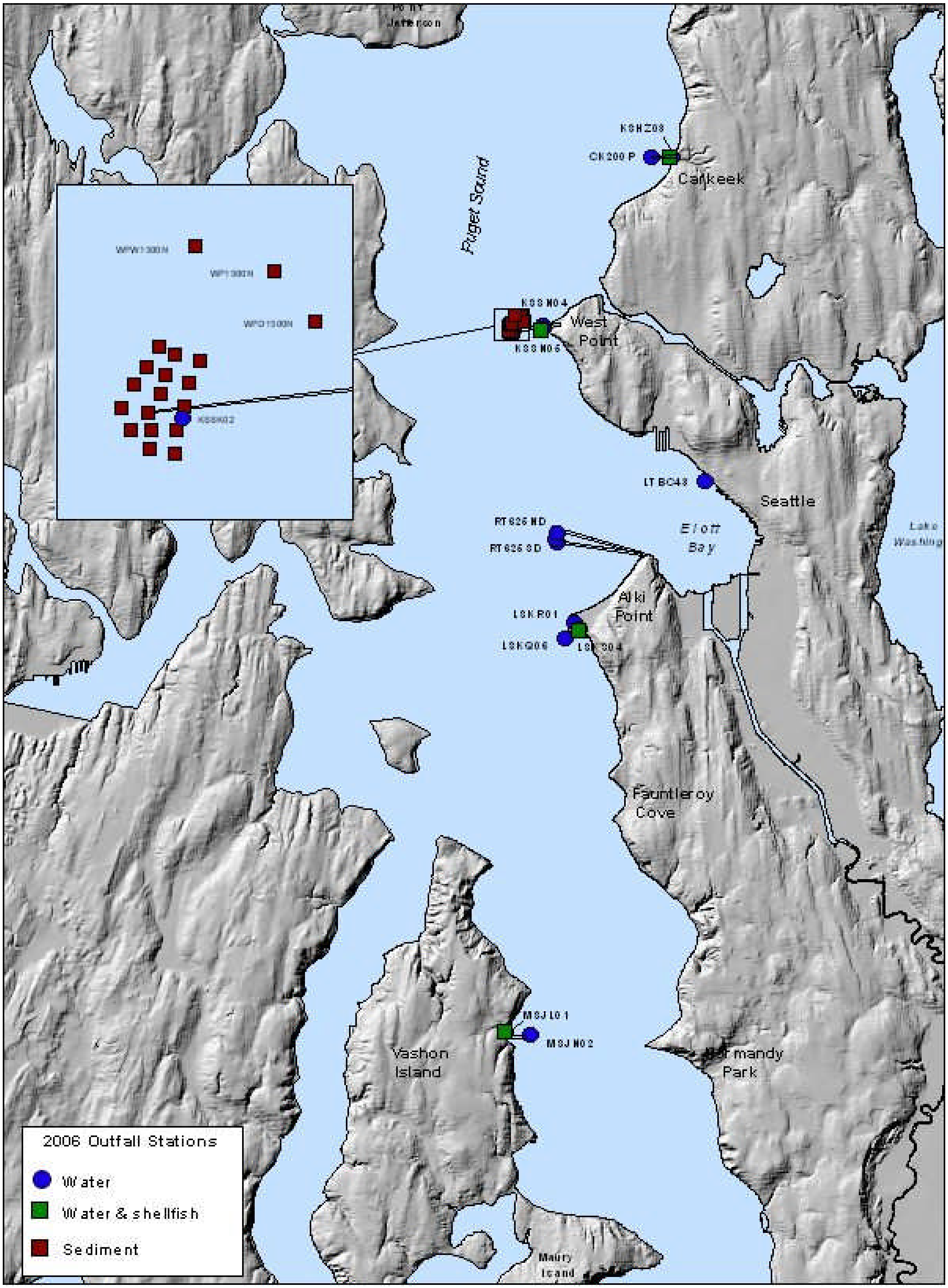

Figure 2-2. 2006 Outfall Monitoring Station Locations (see Table 2-1 for West Point locators)

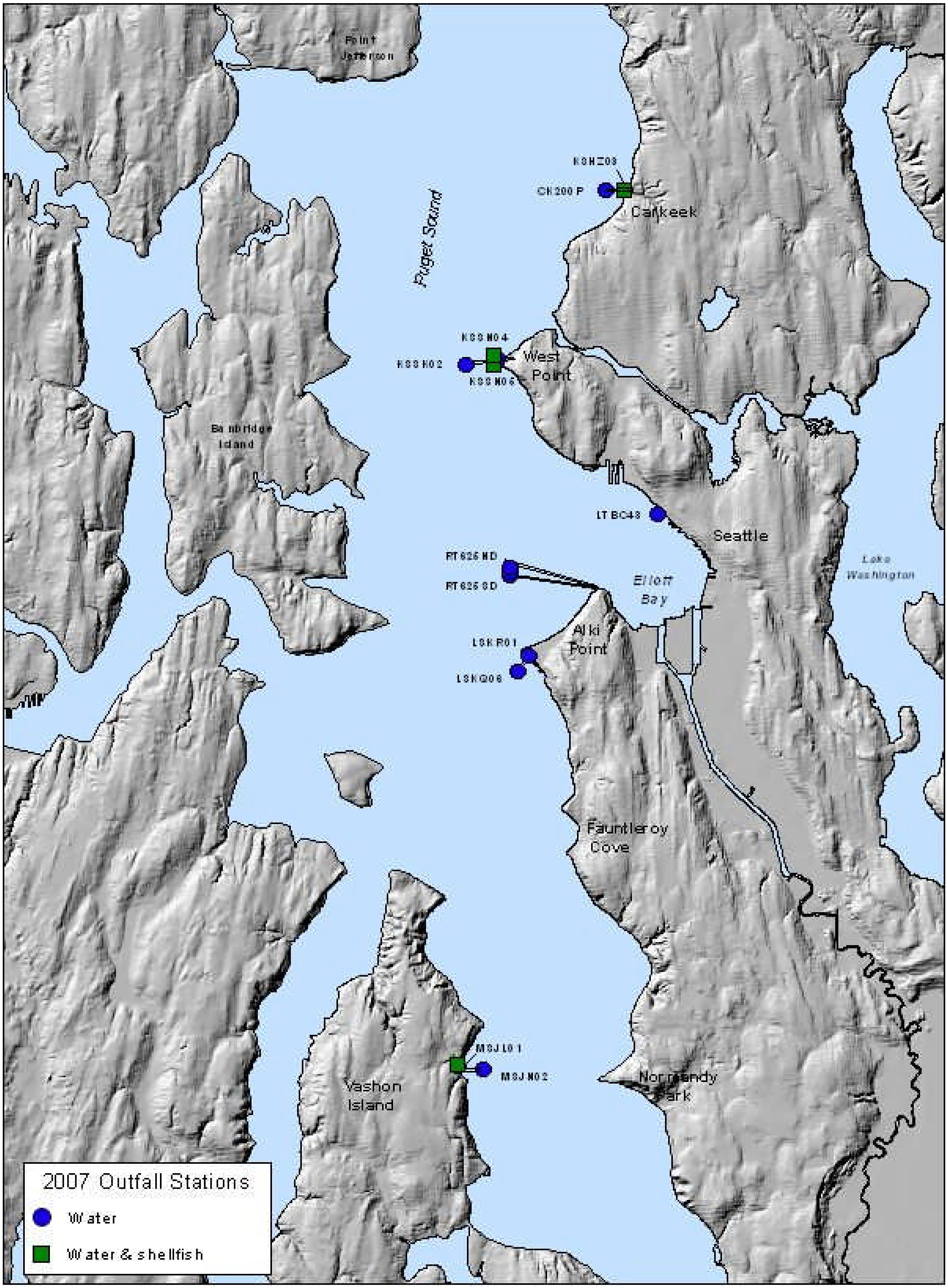

Figure 2-3. 2007 Outfall Monitoring Station Locations

A new sampling station (MSJN02) was established in 2005 at the end of the newly constructed Vashon TP outfall and the previous station (VO50E) discontinued.

Locations for outfall water stations were based upon the following: stations KSSK02, LSEP01, MSJN02, LTBC43, CK200P, and LSKQ06 were established in the water column at the end of outfall pipes. Station KSSK02 is located at the end of the West Point TP outfall diffuser, LSEP01 is located at the end of the South Plant's north diffuser, MSJN02 is at the end of the Vashon TP outfall, LTBC43 is at the end of the Denny Way/Elliott West CSO long outfall pipe, CK200P is at the end of the Carkeek CSO TP outfall, and LSKQ06 is located at the end of the Alki CSO TP outfall. Stations RT625ND and RT625SD were established at the mid-diffuser point for the north and south South TP outfall pipes, respectively. Stations were placed at these locations in order to characterize water quality at the point where effluent is discharged into the marine environment.

The three West Point TP sediment transects were based upon the following: one transect was placed at the mid-diffuser point (approximately 200 ft east of the end of the outfall), one at the end of the outfall, and another 200 ft west of the end of the outfall. All three transects were placed in a north-to-south alignment as the currents in this area are in a net north direction. The farthest northern sampling point along each transect was placed 645 ft north of the center of the outfall and the farthest south was placed 430 ft south of the center of the outfall. Other sampling points along each transect were placed at the outfall, 215 ft both north and south of the outfall, and 430 ft north of the outfall. Three stations placed approximately 1500 ft north of the outfall were sampled to provide baseline reference conditions in the vicinity of the outfall but outside the immediate influence of the effluent plume.

Beach station locations were established along the shoreline in the vicinity of treatment plant outfalls. Stations were placed at these locations in order to evaluate water and sediment quality at beach sites in the vicinity of effluent discharges. Two stations, KSSN04 and KSSN05, are located on the north and south side of West Point, respectively. Station LSKR01 is located north of the location where the Alki CSO TP outfall exits the shoreline. Station MSJL01 is located on the beach directly west of the Vashon TP outfall and KSHZ03 is located directly east of the Carkeek CSO TP outfall. A beach station is not located near the South TP outfall as the outfall is over 10,000 feet offshore.

A summary of parameters measured and the frequency sampled for each station is provided in Tables 2-1 through 2-3. Offshore water samples were collected monthly to assess seasonal trends for the following parameters: temperature, salinity, turbidity, water clarity, dissolved oxygen, nutrients (ammonia-nitrogen, nitrate+nitrite, total phosphorus, and silica), chlorophyll-*a*, pheophytin-*a*, total suspended solids, photosynthetically active radiation, and fecal indicator bacteria (fecal coliforms and enterococci). Beach waters were analyzed monthly for fecal indicator bacteria, temperature, salinity, and nutrients (ammonia-nitrogen, nitrate+nitrite, total phosphorus, and silica) in order to evaluate seasonal trends for these parameters.

Beach sediments were collected in August of 2005 and analyzed for organic compounds, metals, and conventional parameters (total organic carbon, total solids, total volatile solids, and grain size). In 2005, shellfish tissues were analyzed in August for organic compounds, metals, and conventional parameters (total solids and percent lipids). Beginning in 2006, shellfish tissues were collected in March as well as August to assess seasonal differences. Prior to discontinuing the sampling program for macroalgae in 2006, samples were collected and analyzed for metals in 2005.

Table 2-1. 2005 Outfall Stations, Parameters, and Frequency Measured

			SEDIMENT			WATER		SHELLFISH			ALGAE
STATION	LOCATION	OFFSHORE/ BEACH	Organics	Metals	Conventionals	Bacteria	GWQP *	Organics	Metals	Conventionals	Metals
KSHZ03	Carkeek	Beach	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12	◆ 1	◆ 1	◆ 1	◆ 1
CK200P	Carkeek	Offshore				◆ 12	◆ 12				
KSSN04	West Point	Beach				◆ 12					◆ 1
KSSN05	West Point	Beach	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12	◆ 1	◆ 1	◆ 1	◆ 1
KSSK02	West Point outfall	Offshore				◆ 12	◆ 12				
LTBC43	Denny Way outfall	Offshore				◆ 12	◆ 12				
LSEP01	South Plant outfall	Offshore				◆ 12	◆ 12				
LSKR01	Alki Point	Beach				◆ 12					
LSKS01	Alki	Beach	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12	◆ 1	◆ 1	◆ 1	◆ 1
LSKQ06	Alki outfall	Offshore				◆ 12	◆ 12				
MSJN02	Vashon I. Outfall	Offshore				◆ 12	◆ 12				
MSJL01	Vashon Island	Beach	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12	◆ 1	◆ 1	◆ 1	◆ 1

* GWQP = general water quality parameters. Includes nutrients, salinity, temperature, chlorophyll, dissolved oxygen, solids, transparency, photosynthetically active radiation for offshore waters; nutrients, salinity, temperature for beach waters.
Shellfish conventionals include total solids and percent lipids.
Sediment conventionals include total solids, organic carbon, sulfides, ammonia, and grain size distribution.
Numbers indicate frequency sampled per year on a monthly basis.

2.1.2 Marine Ambient Monitoring Program

The ambient program provides background information for comparison to data obtained from the King County outfall monitoring program and contributes to a long-term dataset which enables overall Puget Sound water quality trends to be evaluated.

Offshore water column samples were collected during 2005, 2006, and 2007 for the ambient monitoring program. Beach water and shellfish tissue were also collected all three years. Macroalgae tissues were collected in 2005, however, the macroalgae sampling program was discontinued in 2006. Beach sediments were also collected in 2005 but not in 2006 or 2007. Beginning in 2005, beach sediments at both ambient and outfall sites are collected on a five-year cycle. Water samples were collected from multiple depths at the offshore stations and from a single depth at the beach stations. In 2007, offshore sediments were collected in Puget Sound and Elliott Bay as part of the ambient sediment monitoring program. Station locations are shown in Figures 2-4 through 2-6 and station coordinates are provided in Appendix E.

Table 2-2. 2006 Outfall Stations, Parameters, and Frequency Measured

STATION	LOCATION	OFFSHORE/ BEACH	SEDIMENT: Organics	SEDIMENT: Metals	SEDIMENT: Conventionals	SEDIMENT: Benthic infauna	WATER: Bacteria	WATER: GWQP *	SHELLFISH: Metals	SHELLFISH: Conventionals
KSHZ03	Carkeek	Beach					◆ 12	◆ 12	◆ 2	◆ 2
CK200P	Carkeek	Offshore					◆ 12	◆ 12		
KSSN04	West Point	Beach					◆ 12	◆ 12		
KSSN05	West Point	Beach					◆ 12	◆ 12	◆ 2	◆ 2
KSSK02	West Point outfall	Offshore					◆ 12	◆ 12		
WP230P	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WP215N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WP215S	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WP430N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WP430S	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WP645N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	1				
WP1500N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WP230D	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WPD215N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	1				
WPD215S	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	1				
WPD430N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WPD430S	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WPD1500N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	1				
WP280W	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	1				
WPW215N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WPW215S	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WPW430N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	1				
WPW645N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	1				
WPW1500N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	1				
LTBC43	Denny Way outfall	Offshore					◆ 12	◆ 12		
RT625ND	South Plant north outfall	Offshore					◆ 12	◆ 12		
RT625SD	South Plant south outfall	Offshore					◆ 12	◆ 12		
LSKR01	Alki north	Beach					◆ 12	◆ 12		
LSKS04	Alki south	Beach					◆ 12	◆ 12	◆ 2	◆ 2
LSKQ06	Alki outfall	Offshore					◆ 12	◆ 12		
MSJN02	Vashon I. Outfall	Offshore					◆ 12	◆ 12		
MSJL01	Vashon Island	Beach					◆ 12	◆ 12	◆ 2	◆ 2

* GWQP = general water quality parms. Includes nutrients, salinity, temperature, chlorophyll, dissolved oxygen, solid transparency, photosynthetically active radiation for offshore waters; nutrients, salinity, temp. for beach waters.
Shellfish conventionals include total solids and percent lipids.
Sediment conventionals include total solids, organic carbon, sulfides, ammonia, and grain size distribution.
Numbers indicate frequency sampled per year on a monthly basis.

Table 2-3. 2007 Outfall Stations, Parameters, and Frequency Measured

			SEDIMENT			WATER		SHELLFISH	
STATION	LOCATION	OFFSHORE/ BEACH	Organics	Metals	Conventionals	Bacteria	GWQP *	Metals	Conventionals
KSHZ03	Carkeek	Beach				◆ 12	◆ 12	◆ 2	◆ 2
CK200P	Carkeek	Offshore				◆ 12	◆ 12		
KSSN04	West Point	Beach				◆ 12	◆ 12	◆ 2	◆ 2
KSSN05	West Point	Beach				◆ 12	◆ 12	◆ 2	◆ 2
KSSK02	West Point outfall	Offshore				◆ 12	◆ 12		
KSYV02	Magnolia CSO	Beach				◆ 12	◆ 12		
LTBC43	Denny Way outfall	Offshore				◆ 12	◆ 12		
LSEP01	South Plant outfall	Offshore				◆ 12	◆ 12		
LSKR01	Alki north	Beach				◆ 12	◆ 12		
LSKQ06	Alki outfall	Offshore				◆ 12	◆ 12		
MSJN02	Vashon I. Outfall	Offshore				◆ 12	◆ 12		
MSJL01	Vashon Island	Beach				◆ 12	◆ 12	◆ 2	◆ 2

* GWQP = general water quality parameters. Includes nutrients, salinity, temp., chlorophyll, dissolved oxygen, solids, transparency, photosynthetically active radiation for offshore waters; nutrients, salinity, temp. for beach waters.
Shellfish conventionals include total solids and percent lipids.
Numbers indicate frequency sampled per year on a monthly basis.

The majority of the ambient stations sampled in 2005 were also sampled in 2006 and 2007. Three beach stations sampled in 2005 were discontinued after an assessment of previous sample results and/or an unnecessary high sample resolution in a particular area. Ten beach stations were added to the ambient program in 2007 to increase spatial coverage within King County waters. Other ambient beach locations were sampled for various reasons, such as a high-use public beach, potential to have water quality problems, and continuation of a long-term dataset. Locations for offshore water samples were chosen based on continuation of a long-term dataset (stations KSBP01 and LSNT01) and spatial coverage to assess water conditions within the Central Basin.

King County's previous ambient subtidal sediment monitoring program evaluated sediment quality at four stations in Elliott Bay, two stations in the Puget Sound Central Basin, and one station in Shilshole Bay. Samples were collected from these stations biennially between 1996 and 2004 and annually at several of the stations, as well as others, prior to 1996.

The former subtidal sediment monitoring program was temporarily discontinued after 2004 to allow King County staff scientists to evaluate data generated from the program as well as other data collection efforts within the region. Following this review period, King County expanded its marine ambient subtidal sediment monitoring program to focus on sediment quality in Elliott Bay, while still monitoring truly ambient sediment quality in the Central Basin of Puget Sound as well as three smaller embayments of interest.

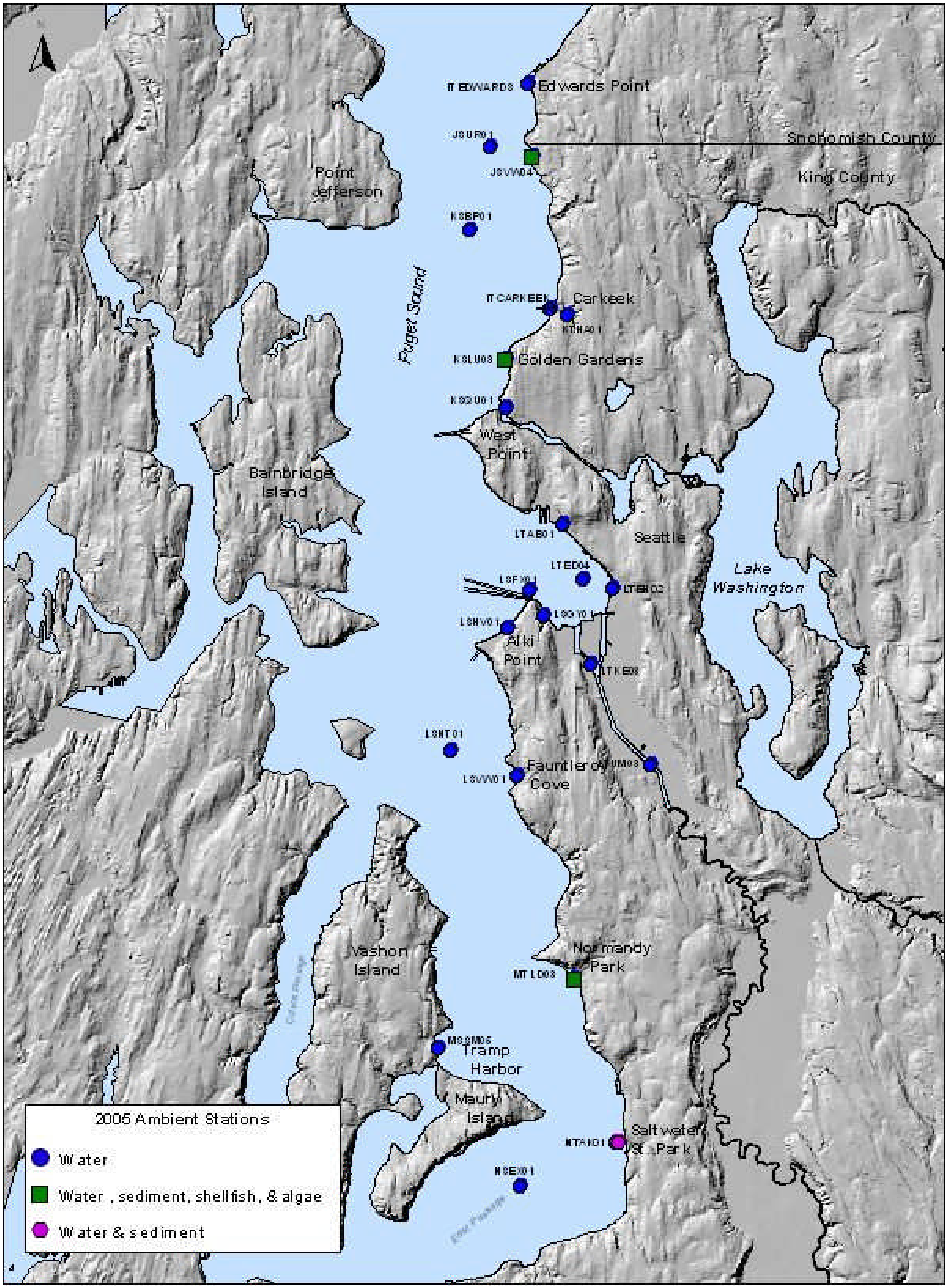

Figure 2-4. 2005 Ambient Monitoring Station Locations

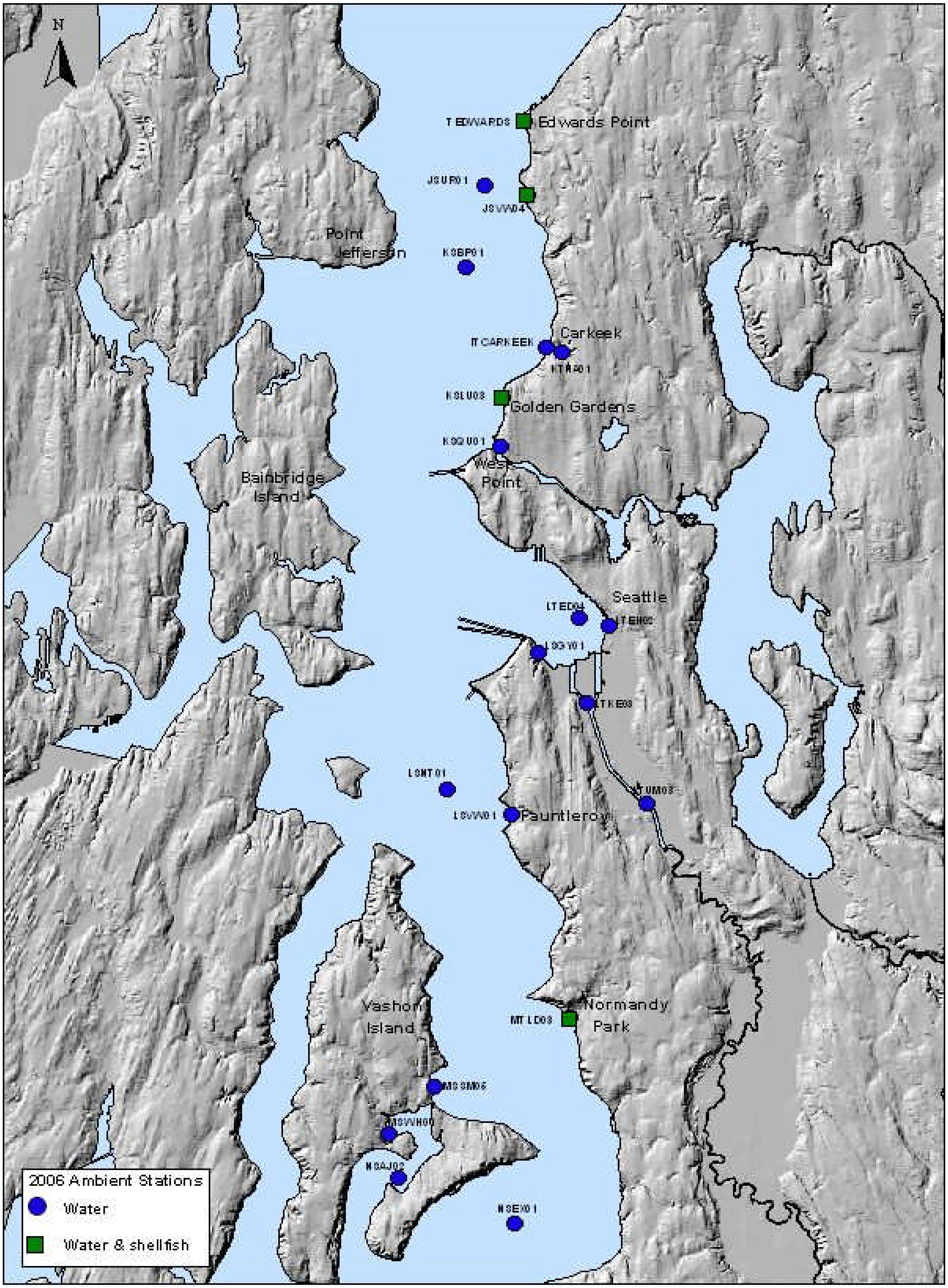

Figure 2-5. 2006 Ambient Monitoring Station Locations

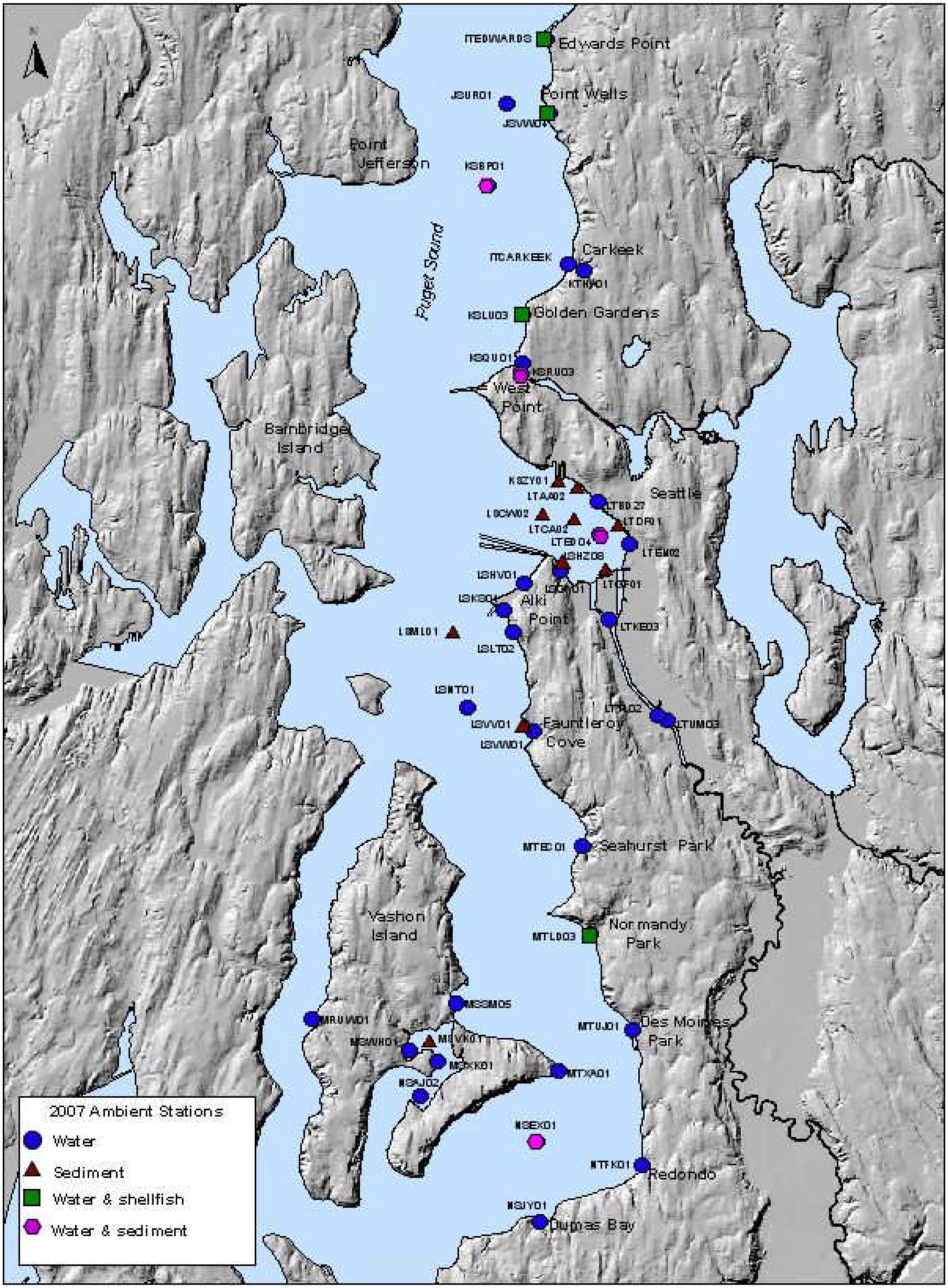

Figure 2-6. 2007 Ambient Monitoring Station Locations

The Central Basin and associated smaller embayments sediment program will include six sites sampled every five years. The frequency of sampling for these six stations should be sufficient to monitor long-term trends in sediment quality. The three stations in the Central Basin which represent ambient sediment conditions in the deep, depositional areas of Puget Sound include:

- Station KSBP01 located off of Point Jefferson. This station represents conditions in the northern area of the Central Basin and is one of King County's long-term water column monitoring stations.
- Station LSML01 located off of West Seattle. This station represents conditions in the middle of the Central Basin and is one of King County's long-term sediment monitoring stations.
- Station NSEX01 located in East Passage. This station represents conditions in the southern area of the Central Basin and is another of King County's long-term water column monitoring stations.

The three stations located in the small embayments which represent specific areas of interest due to potential anthropogenic impacts include:

- Station LSRU03 located in outer Salmon Bay, just downstream from the Hiram Chittenden locks. This area receives a high level of small and large vessel traffic entering and exiting the locks.
- Station LSVV01 located in Fauntleroy Cove. This area has a history of water quality issues, receives a large amount of freshwater input, and is impacted by ferry traffic at the Fauntleroy ferry dock.
- Station MSVK01 located in inner Quartermaster Harbor. This area is of importance as habitat for a variety of species, including wintering birds and Pacific herring. This shallow, quiescent embayment receives a moderate amount of seasonal small vessel traffic.

The Elliott Bay sediment monitoring program includes eight stations with sampling occurring every two years. This more-frequent sampling will allow King County and other decision-makers to better evaluate temporal changes in sediment quality and help assess the potential positive impacts to the marine environment from various sediment cleanup projects and other improvements in Elliott Bay. Four Elliott Bay stations have long-term sediment quality data sets that will continue with the new sampling program and form a rough east-west transect away from areas of potential point-source impacts. These stations are:

- LSCW02 located at the hypothetical boundary-line between Elliott Bay and the Central Basin of Puget Sound;
- LTCA02 located in the center of Elliott Bay;
- LTED04 located in the center of Elliott Bay, inshore of LTCA02; and
- LTDF01 located along the central Seattle waterfront, near Pier 66.

Four new Elliott Bay stations have been added to the monitoring program to assess specific areas of the bay. These stations are:

- KSZY01 located just offshore of Piers 90/91. This area has historically received high heavy-vessel traffic and will continue to receive large ships when cruise liners begin using these docking facilities.
- LTAA02 located just offshore of the grain terminal. This area has also historically received high heavy-vessel traffic and docking.

- LTGF01 located just offshore of the northern end of Harbor Island. This location is in an area of heavy industry, including fuel storage and transfer, shipbuilding and repair, and the transportation industry.
- LSHZ08 located just offshore of Cove 2 at Seacrest Park. This area has high usage by recreational SCUBA divers, including diving classes, which includes a high incidence of primary contact with bottom sediments, especially by student divers.

Ambient offshore water samples were collected monthly to assess seasonal trends for the following parameters: temperature, salinity, turbidity, water clarity, dissolved oxygen, nutrients (ammonia-nitrogen, nitrate+nitrite, total phosphorus, and silica), chlorophyll-*a*, pheophytin-*a*, total suspended solids, photosynthetically active radiation, and fecal indicator bacteria (fecal coliforms and enterococci). In 2005, water samples collected from all beach sites were analyzed monthly for fecal indicator bacteria and temperature. Samples from five beach sites were also analyzed monthly for salinity, and nutrients (ammonia-nitrogen, nitrate+nitrite, total phosphorus, and silica) in order to evaluate seasonal trends for these parameters. Beginning in 2006, all beach waters were analyzed for the full suite of parameters listed above.

Beach sediments were collected at four locations in August 2005 and analyzed for organic compounds, metals, and conventional parameters (total organic carbon, total solids, total volatile solids, and grain size). Shellfish tissues from three sites in 2005 were analyzed for organic compounds, metals, and conventional parameters (total solids and percent lipids). In 2006 and 2007, shellfish tissues from four sites were analyzed for metals and conventional parameters. Organic compounds were not analyzed in shellfish tissues in 2006 and 2007 as they were rarely detected. Macroalgae samples were analyzed for metals in 2005 only. Shellfish and algae samples were collected in August and beginning in 2006, shellfish were also collected in March. A summary of parameters measured and the frequency sampled for each station is provided in Tables 2-4 through 2-6.

Near the end of November 2007, a high-frequency water quality data acquisition system was installed at the Seattle Aquarium along the Seattle waterfront in Elliott Bay (station SEAQYSI). This site was chosen to be representative of inner Elliott Bay. Salinity, temperature, dissolved oxygen, turbidity, chlorophyll, and depth data are collected every 15 minutes at two depths and telemetered to a website. The top depth is approximately one meter below the water surface and the bottom depth is approximately 10 meters below the water surface. In addition, meteorological parameters (wind speed and direction, air temperature, precipitation, solar radiation, and relative percent humidity) are also collected every 15 minutes. Data are available at the following website: http://green.kingcounty.gov/marine/HiFrequency.htm. As only about a month of data were collected during 2007 at this site, results from station SEAQYSI will be discussed in the 2008 Water Quality Status Report for Marine Waters.

Table 2-4. 2005 Ambient Stations, Parameters, and Frequency Measured

			SEDIMENT			WATER		SHELLFISH			ALGAE
STATION	**LOCATION**	**OFFSHORE/ BEACH**	**Organics**	**Metals**	**Conventionals**	**Bacteria**	**GWQP ***	**Organics**	**Metals**	**Conventionals**	**Metals**
ITEDWARDSPT	Edwards Point	Beach				◆ 12	◆ 12				
JSUR01	Point Wells	Offshore				◆ 12	◆ 12				
JSVW04	Point Wells	Beach	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12	◆ 1	◆ 1	◆ 1	◆ 1
KSBP01	Point Jefferson	Offshore				◆ 12	◆ 12				
ITCARKEEKP	Carkeek Park	Beach				◆ 12	◆ 12				
KTHA01	Piper's Creek	Creek				◆ 12	◆ 12				
KSLU03	Golden Gardens	Beach	◆ 1	◆ 1	◆ 1	◆ 12		◆ 1	◆ 1	◆ 1	◆ 1
KSQU01	Shilshole Bay	Beach				◆ 12					
LTAB01	inner Elliott Bay	Beach				◆ 12					
LTEH02	inner Elliott Bay	Beach				◆ 12					
LTKE03	West Waterway	River				◆ 12	◆ 12				
LTUM03	Duwamish River	River				◆ 12	◆ 12				
LSGY01	Seacrest	Beach				◆ 12					
LSFX01	Duwamish Head	Beach				◆ 12					
LTED04	Elliott Bay	Offshore				◆ 12	◆ 12				
LSHV01	West Seattle	Beach				◆ 12					
LSNT01	Dolphin Point	Offshore				◆ 12	◆ 12				
LSVW01	Fauntleroy Cove	Beach				◆ 12	◆ 12				
MTLD03	Normandy Park	Beach	◆ 1	◆ 1	◆ 1	◆ 12		◆ 1	◆ 1	◆ 1	◆ 1
MSSM05	Tramp Harbor	Beach				◆ 12					
NTAK01	Saltwater St. Park	Beach	◆ 1	◆ 1	◆ 1	◆ 12					
NSEX01	East Passage	Offshore				◆ 12	◆ 12				

* GWQP = general water quality parameters. Includes nutrients, salinity, temperature, chlorophyll, dissolved oxygen, solids, transparency, photosynthetically active radiation for offshore waters. Includes nutrients, salinity, temperature for beach waters.

Shellfish conventionals include total solids and percent lipids.

Sediment conventionals include total solids, organic carbon, sulfides, ammonia, and grain size distribution.

Numbers indicate frequency sampled per year on a monthly basis.

Table 2-5. 2006 Ambient Stations, Parameters, and Frequency Measured

			SEDIMENT			WATER		SHELLFISH	
STATION	LOCATION	OFFSHORE/ BEACH	Organics	Metals	Conventionals	Bacteria	GWQP *	Metals	Conventionals
ITEDWARDSPT	Edwards Point	Beach				◆ 12	◆ 12	◆ 2	◆ 2
JSUR01	Point Wells	Offshore				◆ 12	◆ 12		
JSVW04	Point Wells	Beach				◆ 12	◆ 12	◆ 2	◆ 2
KSBP01	Point Jefferson	Offshore				◆ 12	◆ 12		
ITCARKEEKP	Carkeek Park	Beach				◆ 12	◆ 12		
KTHA01	Piper's Creek	Creek				◆ 12	◆ 12		
KSLU03	Golden Gardens	Beach				◆ 12	◆ 12	◆ 2	◆ 2
KSQU01	Shilshole Bay	Beach				◆ 12	◆ 12		
LTEH02	inner Elliott Bay	Beach				◆ 12	◆ 12		
LTKE03	West Waterway	River				◆ 12	◆ 12		
LTUM03	Duwamish River	River				◆ 12	◆ 12		
LSGY01	Seacrest	Beach				◆ 12	◆ 12		
LTED04	Elliott Bay	Offshore				◆ 12	◆ 12		
LSNT01	Dolphin Point	Offshore				◆ 12	◆ 12		
LSVW01	Fauntleroy Cove	Beach				◆ 12	◆ 12		
MTLD03	Normandy Park	Beach				◆ 12	◆ 12	◆ 2	◆ 2
MSSM05	Tramp Harbor	Beach				◆ 12	◆ 12		
MSWH01	Quartermaster Hbr.	Offshore				◆ 12	◆ 12		
NSAJ02	Quartermaster Hbr.	Offshore				◆ 12	◆ 12		
NSEX01	East Passage	Offshore				◆ 12	◆ 12		

* GWQP = general water quality parameters.Includes nutrients, salinity, temp., chlorophyll, dissolved oxygen, solids, transparency, photosynthetically active radiation for offshore waters. Includes nutrients, salinity, temp. for beach waters.

Shellfish conventionals include total solids and percent lipids.

Numbers indicate frequency sampled per year on a monthly basis.

Table 2-6. 2007 Ambient Stations, Parameters, and Frequency Measured

			SEDIMENT			WATER		SHELLFISH	
STATION	LOCATION	OFFSHORE/ BEACH	Organics	Metals	Conventionals	Bacteria	GWQP *	Metals	Conventionals
ITEDWARDSPT	Edwards Point	Beach				◆ 12	◆ 12	◆ 2	◆ 2
JSUR01	Point Wells	Offshore				◆ 12	◆ 12		
JSVW04	Point Wells	Beach				◆ 12	◆ 12	◆ 2	◆ 2
KSBP01	Point Jefferson	Offshore	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12		
ITCARKEEKP	Carkeek Park	Beach				◆ 12	◆ 12		
KTHA01	Piper's Creek	Creek				◆ 12	◆ 12		
KSRU03	Salmon Bay	Offshore	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12		
KSLU03	Golden Gardens	Beach				◆ 12	◆ 12	◆ 2	◆ 2
KSQU01	Shilshole Bay	Beach				◆ 12	◆ 12		
LTBD27	inner Elliott Bay	Beach				◆ 12	◆ 12		
LTEH02	inner Elliott Bay	Beach				◆ 12	◆ 12		
LTAA02	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1				
LSCW02	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1				
LSHZ08	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1				
LTCA02	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1				
LTDF01	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1				
KSZY01	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1				
LTGF01	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1				
LTED04	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12		
LTKE03	West Waterway	River				◆ 12	◆ 12		
LTUM03	Duwamish River	River				◆ 12	◆ 12		
LTTL02	Duwamish River	River				◆ 12	◆ 12		
LSGY01	Seacrest	Beach				◆ 12	◆ 12		
LSHV01	Alki Beach	Beach				◆ 12	◆ 12		
LSKS01	Richey Viewpoint	Beach				◆ 12	◆ 12		
LSLT02	Mee-Kwa-Mooks	Beach				◆ 12	◆ 12		
LSML01	Central Basin	Offshore	◆ 1	◆ 1	◆ 1				
LSNT01	Dolphin Point	Offshore				◆ 12	◆ 12		
LSVV01	Fauntleroy Cove	Offshore	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12		
LSVW01	Fauntleroy Cove	Beach				◆ 12	◆ 12		
MTEC01	Seahurst Park	Beach				◆ 12	◆ 12		
MTLD03	Normandy Park	Beach				◆ 12	◆ 12	◆ 2	◆ 2
MSSM05	Tramp Harbor	Beach				◆ 12	◆ 12		
MRUW01	Lisabuela Pk	Beach				◆ 12	◆ 12		
MTUJ01	Des Moines Pk	Beach				◆ 12	◆ 12		
MSXK01	Burton Acres	Beach				◆ 12	◆ 12		
MTXA01	Point Robinson	Beach				◆ 12	◆ 12		
MSVK01	Quartermaster Hbr.	Offshore	◆ 1	◆ 1	◆ 1				
MSWH01	Quartermaster Hbr.	Offshore				◆ 12	◆ 12		
NSAJ02	Quartermaster Hbr.	Offshore				◆ 12	◆ 12		
NSEX01	East Passage	Offshore	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12		
NTFK01	Redondo Beach	Beach				◆ 12	◆ 12		
NSJY01	Dumas Bay	Beach				◆ 12	◆ 12		

* GWQP = general water quality parameters. Includes nutrients, salinity, temp., chlorophyll, dissolved oxygen, solids, transparency, photosynthetically active radiation for offshore waters.Includes nutrients, salinity, temp. for beach waters. Numbers indicate frequency sampled per year.

Shellfish conventionals include total solids and percent lipids. Sediment conventionals include total solids, organic carbon, sulfides, ammonia, and grain size distribution.

2.2 Water Column Monitoring

Water column monitoring at outfall and ambient sites is an important component of the County's water quality monitoring program and is structured to detect natural seasonal changes in the water column as well as to identify changes from anthropogenic inputs. General water quality parameters, including temperature, salinity, transparency, dissolved oxygen, chlorophyll-*a*, pheopigment, photosynthetically active radiation, ammonia, nitrate+nitrite, total phosphorus, silica, and total suspended solids, are monitored at multiple depths at each site. Fecal indicator bacteria are monitored at all water column monitoring sites.

2.2.1 Bacteria

Biologists and agencies responsible for protecting public health define water quality in terms of several variables, including the presence of certain types of bacteria. Fecal coliforms are found in the intestinal tract and feces of humans and other warm-blooded animals. These bacteria may enter the aquatic environment directly from humans and animals, agricultural and stormwater runoff, and wastewater. Although fecal coliform bacteria are usually not pathogenic, they may occur along with disease-causing bacteria and thereby serve as an indicator of the potential for pathogens to be present. Generally, a high fecal coliform count indicates a greater possibility for pathogens to be present. Fecal coliforms are typically found in higher numbers than pathogens and are easier and safer to analyze in the laboratory.

In Washington State, regulatory standards have been established for acceptable levels of fecal coliforms for various water uses, including recreation and fish and wildlife habitat. It should be noted that although fecal coliforms are commonly used as an indicator for the presence of pathogens, there are limitations to the use of these data. There is no recognized numeric association between the number of fecal coliforms and the number of pathogenic bacteria measured in a sample. In addition, the presence of viruses and naturally occurring toxic organisms (such as certain dinoflagellates) is not indicated by the presence of fecal coliforms, so these organisms must be measured independently.

Enterococci, like fecal coliforms, are also found in the intestinal tract of warm-blooded mammals and birds and are also used as an indicator for the presence of pathogens. As with fecal coliforms, there is no recognized numeric association between the amount of enterococci and the amount of pathogenic bacteria measured in a sample. The U.S. Environmental Protection Agency (EPA) recommends the use of enterococci as the indicator for potential human health risks at marine swimming beaches, however, Washington State uses fecal coliforms as the bacterial indicator organism for reasons described in Section 2.6.2. King County measures both fecal coliform and enterococci bacteria as part of the marine monitoring program.

2.2.2 Temperature and Salinity

Water temperature is an important factor in an estuary. As water temperature rises, biological and chemical activity generally increases, while the capacity of water to hold dissolved oxygen decreases. Water temperature is dependent upon various factors including depth, season, amount of tidal mixing, wind, storms, amount of freshwater input, and degree of vertical stratification.

Both temperature and salinity influence water column stratification, although salinity is more important in determining stratification in estuaries due to its effect on density. Estuaries usually exhibit changes in salinity as freshwater input increases or decreases. Salinity also fluctuates with tides, the input of high salinity water from deep Pacific oceanic water, precipitation, and degree of water column mixing from winds. Generally, salinity increases with water depth unless the estuary is well-mixed.

2.2.3 Dissolved Oxygen

Dissolved oxygen is an important factor controlling the presence or absence of marine species. Aquatic plants and animals require a certain amount of oxygen dissolved in the water for respiration and basic metabolic processes. Waters with high concentrations of dissolved oxygen are generally considered healthy ecosystems and are capable of sustaining many species of aquatic organisms.

Several factors influence dissolved oxygen concentrations. Seasonal climatic fluctuations can cause water temperature to rise in the spring and summer, reducing the capacity of water to hold dissolved oxygen. In winter, deep oceanic water from the Pacific Ocean containing naturally low levels of oxygen enters Puget Sound. Moreover, anthropogenic input of organic matter and phytoplankton decay may also decrease levels of oxygen. Most bacteria that utilize organic matter for food consume dissolved oxygen. Hypoxia results when the rate of oxygen consumption, mostly by bacteria decomposing organic material in the water column, exceeds the rate of oxygen production by photosynthesis and by replenishment at the air/water interface. When the system is overloaded with organic material, oxygen consumption by bacteria may increase to the point where conditions can no longer support marine life.

2.2.4 Transparency

Transparency, or water clarity, is measured to determine the euphotic zone, the depth at which light capable of supporting plant growth penetrates the water column. Several factors affect transparency, including the amount of suspended silt and soil particles (measured as total suspended solids) and the amount of phytoplankton and zooplankton in the water column. Silt from streams and rivers (particularly after storms) stirred up by wave action also affects transparency. Low transparency conditions that persist over an extended period of time can degrade the health of a water body as the decreased amount of light penetration reduces the area in which aquatic plants and primary producers can grow. In addition, many marine organisms feed by filtering water and large amounts of suspended matter may obstruct their filter-feeding systems.

2.2.5 Photosynthetically Active Radiation (PAR)

Sunlight consists of a wide spectrum of wavelengths, of which only a small portion can be used for photosynthesis. This small range of light energy available for photosynthesis is in the 400 to 700 nanometer range. Photosynthetically active radiation (also referred to as light intensity) is measured at various depths throughout the water column to determine the amount of light energy available to phytoplankton, macrophytes, and some diatoms for photosynthesis. PAR is an important factor as phytoplankton and other plants can only grow in the water column where enough light penetrates to support photosynthesis. Turbidity, waves, and atmospheric conditions are factors which may affect PAR levels.

2.2.6 Nutrients

The addition of nutrients, such as nitrogen and phosphorus, into marine waters can have a considerable effect on water quality. This is particularly true in nearshore habitats where most nutrient input typically occurs. Nutrients may enter marine waters from wastewater discharges, nonpoint runoff, and riverine and oceanic sources. The greatest impact these nutrients may have is a sudden increase in aquatic plant growth.

The amount of light that penetrates the water column and the amount of nutrients in the water column affect phytoplankton growth. Nitrogen is the primary limiting nutrient that determines the growth of phytoplankton in marine waters (Valiela, 1984). Although nitrogen occurs naturally in the marine environment, increases from sources such as wastewater or fertilizers can cause increases in phytoplankton growth, particularly in areas with reduced circulation. An increase in phytoplankton biomass may cause a decline in dissolved oxygen as the phytoplankton cells respire and decay. This depression in dissolved oxygen can become critical to non-motile marine organisms. The marine waters within King County have not experienced significant eutrophication problems, mainly due to the high degree of mixing in the Central Basin of Puget Sound (PSWQAT, 2000).

Nitrogen Compounds. Nitrate, nitrite, and ammonium ion are forms of inorganic nitrogen used by phytoplankton in the aquatic environment. Nitrates and nitrites are formed through the oxidation of ammonium ion by nitrifying bacteria. As noted above, nitrogen is usually the limiting nutrient in marine waters. Therefore, an increase in nitrogen compounds could lead to phytoplankton blooms. When blooms occur, water conditions (such as reduced water clarity and dissolved oxygen) may become unfavorable for aquatic organisms. Input of nitrogen compounds may originate from sources such as wastewater from municipal discharges, stormwater runoff, septic systems, agricultural runoff, oceanic input, and atmospheric deposition.

Phosphorus. Phosphorus is an essential element for aquatic plants and a fundamental element in the metabolic process for both plants and animals. Total phosphorus includes both organic phosphorus and inorganic phosphate. Inorganic phosphates are rapidly taken up by algae and other aquatic plants, although phosphates are usually not the limiting nutrient in marine waters. However, large inputs could cause algal blooms leading to unfavorable conditions. Potential sources of phosphorus entering the marine environment include wastewater from municipal discharges, industrial wastes, nonpoint agricultural and urban runoff, rivers and streams, and the Pacific Ocean.

Silica. Silica is a micronutrient needed by diatoms, radiolarians, some sponges, and other siliceous organisms for skeletal growth. Water column silica concentrations can be used as an indicator of plankton blooms, along with chlorophyll-*a*, as silica concentrations in the photic zone will decrease from an increase in phytoplankton uptake. Sediments act as a sink for silica, which may be regenerated by various physical and biological processes and reused by organisms on the seafloor and in overlying waters.

2.2.7 Chlorophyll and Pheopigments

Chlorophyll-*a* is a green pigment produced by algae and other green plants and used during the process of photosynthesis to convert light, carbon dioxide, and water to sugar. Chlorophyll-*a* concentration is an indicator of phytoplankton biomass since all marine planktonic algae contain this photosynthetic pigment. However, chlorophyll-*a* concentrations are not an exact measurement of phytoplankton abundance. The ratio of phytoplankton biomass to chlorophyll varies with species and environmental conditions. Pheopigments, such as pheophorbide-*a* and pheophytin-*a*, are degradation products of chlorophyll and are produced when phytoplankton cells are grazed upon by zooplankton. High concentrations of pheopigments relative to chlorophyll-*a* indicate a high level of grazing in an aquatic ecosystem. Several factors influence phytoplankton abundance including amount of solar radiation, extent of grazing, water temperature, nutrient availability, and water column stratification.

2.2.8 Water Column Sampling Methods

Field Methods. Offshore water column samples were collected by the King County Environmental Services Section in accordance with the *Recommended Guidelines for Sampling Marine Sediment, Water Column, and Tissues in Puget Sound* (PSEP, 1997). The King County Laboratory also has a specific Standard Operating Procedure (SOP) for each type of field sample and data collection process that is available upon request.

Offshore water samples were collected from the *R/V Liberty*, a 42-ft research vessel equipped with a hydraulic crane on the rear deck. Water column profiles were collected using a SeaBird Electronics SBE 25 SEALOGGER conductivity-temperature-depth (CTD) profiler. Parameters measured by the CTD included temperature, salinity, light transmission, dissolved oxygen, photosynthetically active radiation (PAR), and fluorescence (an indicator of chlorophyll-*a* abundance). Density is a calculated parameter using temperature and salinity measurements. The CTD was lowered into the water using a hydraulic boom and allowed to equilibrate for five minutes at the surface before being lowered to a few meters above the seabed. Measurements were collected on the downcast. Multiple five-liter Niskin bottles were mounted onto the rosette containing the CTD profiler for collecting discrete water samples on the upcast at predetermined depths for analysis of nutrients, total suspended solids, bacteria, and quality control samples. The rosette was electronically programmed to close individual bottles at specific depths as the system ascended through the water column. The rosette was then brought on deck and water samples were immediately drawn from the Niskin bottles and placed into appropriate sample containers. Dissolved oxygen samples were immediately preserved with liquid $MnSO_4$ (manganese sulfate) and AIA (alkali iodide azide) and stored in the dark. With the exception of dissolved oxygen bottles that were stored at ambient temperature, sample containers were stored on ice until delivered to the King County Environmental Laboratory.

The two offshore stations in Quartermaster Harbor, MSWH01 and NSAJ02, were sampled from docks rather than by boat. Dissolved oxygen and temperature at these two sites were sampled in the field using a Hydrolab. Water samples for laboratory analysis (salinity, nutrients, bacteria, chlorophyll, suspended solids) were collected using a five-liter Niskin bottle lowered by hand to the selected depth.

Transparency (water clarity) measurements were collected using a 12-inch diameter black and white Secchi disk. Secchi depths were recorded to the nearest 0.1 meter. As readings may vary depending upon environmental conditions (e.g., waves and glare), readings were taken on the shaded and downwind side of the boat to standardize results among individual field personnel and atmospheric conditions as much as possible.

Beach (intertidal) water samples were collected at approximately knee-depth by wading in the water and inverting sample containers just above the water surface, then sinking the bottle down to approximately three to six inches below the water surface. The bottles were not filled completely in order to allow room for mixing. At some sites where accessibility is difficult, such as LSGY01 located in Elliott Bay, samples were collected with a container lowered on a rope from a pier and then transferred into the sample container. Field methods and detection limits are provided in Table 2-7.

Laboratory Methods. Temperature, Secchi disk transparency, and CTD parameters were measured in the field. All other water column parameters were analyzed at the King County Environmental Laboratory. Laboratory methods and detection limits are provided in Table 2-7.
Fecal coliforms and enterococci were analyzed using membrane filtration methodology according to Standard Methods 9222D and 9230C, respectively (APHA, 1998). Quality assurance/quality control procedures included the use of blanks, duplicates, and spikes when appropriate. All data were reviewed prior to entry into the LIMS (Laboratory Information Management System) database.

2.3 Sediment Monitoring

Many pollutants tend to be associated with particles that settle out onto bottom sediments. At sufficient concentrations, these compounds may be harmful to benthic organisms and may bioaccumulate. Sediment monitoring for metals and organic pollutants is part of King County's marine monitoring program. Total solids, total volatile solids, grain size distribution, total organic carbon, ammonia, and total sulfides, referred to as conventional parameters, are also monitored as these parameters affect the bioavailability and/or toxicity of metals and organics as well as influence the concentration of pollutants accumulated. A more detailed description of why sediment conventional parameters are measured is provided below.

Table 2-7. Methods and Detection Limits for Water Samples

		Lab		Field	
Parameter	**Units**	**MDL**	**Method**	**MDL**	**Method**
Salinity	PSS	2.0	SM2520-B	na	CTD:SOP 220v3
Dissolved Oxygen	mg/L	0.5	SM4500-O-C	0.5	CTD:SOP 220v3
Temperature	^oC	--	--	na	CTD:SOP 220v3
PAR	µmol/sm^2	--	--	na	CTD:SOP 220v3
Light Transmission	% light	--	--	0.01	CTD:SOP 220v3
Chlorophyll-*a*	mg/m^3	0.05	EPA 445.0	0.06	CTD:SOP 220v3
Pheophytin-*a*	mg/m^3	0.1	EPA 445.0	--	--
Ammonia-Nitrogen	mg/L	0.01	SM4500-NH3-H	--	--
Nitrate+Nitrite (NO_3+NO_2)	mg/L	0.02	SM4500-NO3-F	--	--
Total Phosphorous	mg/L	0.005	SM4500-P-B,E	--	--
Silica	mg/L	0.05	SM4500-SI-D	--	--
Total Suspended Solids (TSS)	mg/L	0.5	SM2540-D	--	--
Fecal coliform	CFU/100 ml	na	SM9222-D	--	--
Enterococci	CFU/100 ml	na	SM9230-C	--	--

PSS = practical salinity scale
mg/L = milligram per liter
mg/m^3 = milligram per meter cubed
na = not applicable
CFU = colony forming unit
MDL = method detection limit

2.3.1 Total Solids

Total solids are the inorganic and organic particles remaining after a sediment sample has been dried in an oven at 103^o to 105^o Celsius. This parameter is measured to allow the conversion of metals and organic chemical concentrations from wet weight to dry weight for reporting uniformity.

2.3.2 Grain Size Distribution

Grain size distribution is a measure of the size range of particles contained in a given sample. Grain size is usually separated into four main categories: silt, clay, sand, and gravel. The sum of percent silt and clay is referred to as percent fines. Grain size has an influence on chemical concentrations found in sediments and sediments with a large proportion of fine particles tend to have higher chemical concentrations. Grain size also has a large influence on benthic and infaunal community structure.

2.3.3 Total Organic Carbon

Total organic carbon is a measure of the total amount of particulate and nonparticulate organic carbon in a sample. As with grain size, total organic carbon also has an influence on chemical concentrations contained in sediments. The higher the organic carbon content, the higher some chemical concentrations tend to be. This is particularly true for organic compounds.

2.3.4 Total Sulfides

Sulfides are formed by the anaerobic breakdown of organic matter. Total sulfides represent the amount of all sulfide compounds in a given sample. They are measured as they may be toxic to some benthic organisms at low concentrations and can create unaesthetic conditions for humans.

2.3.5 Total Ammonia

Ammonia in sediments can be from natural sources as well as from anthropogenic sources, such as terrestrial runoff and atmospheric deposition of nitrogen. Naturally occurring ammonia is formed by the decomposition of organic matter by bacterial as well as from excreta from organisms living in sediments. Ammonia levels at sufficiently high concentrations may be toxic to marine organisms. are formed by the anaerobic breakdown of organic matter.

2.3.6 Sediment Sampling and Analytical Methods

Field Methods. Offshore sediment samples were collected by the King County Environmental Services Section from the *R/V Liberty*. Samples were collected with two stainless steel 0.1-m^2 modified van Veen grab samplers deployed in tandem. The sampler was decontaminated between sites by scrubbing with a brush to remove excess sediment, followed by an on-board rinsing and thorough *in situ* rinsing. If sample acceptability criteria were met, the top two centimeters of sediment from a minimum of two subsamples (grabs) were composited, homogenized, and placed in the appropriate sample containers. Sediment samples were collected in accordance with the *Puget Sound Estuary Program (PSEP) Recommended Protocols* (PSEP, 1997) and the County's *Standard Protocol for Marine Sediments* (King County, 1997).

Beach (intertidal) sediment sampling locations were determined using a measuring staff, tide chart, and an optical level to sight the proper height on the measuring staff. Samples were collected at +6.5 feet above mean lower low water (MLLW) at each location. If the appropriate tidal elevation was within an area with gravel, cobbles or boulders, then sediments without gravel/cobbles or other large objects closest to the area at the same tidal elevation were sampled instead. Sediment samples were collected using hand-held 2-inch diameter stainless steel coring tubes. Once the required sample amount was obtained, sediments were homogenized in a stainless steel bowl before being transferred to appropriate sample containers. All sampling equipment was pre-cleaned and dedicated sampling tool sets were available for use at each station. All samples were stored on ice until submitted to the laboratory.

Laboratory Methods. The King County Environmental Laboratory analyzed all chemical parameters. Methods and detection limits are provided in Table 2-8. All metals were analyzed using inductively coupled plasma (ICP) emission spectrometry with the exception of mercury, which was analyzed using cold-vapor atomic absorption spectrophotometry (CVAA). Semivolatile organics were extracted with an organic solvent and then analyzed by gas chromatography/mass spectrometry (GC/MS). Pesticides and PCBs were extracted with organic solvents and then analyzed using a gas chromatograph equipped with an electron capture detector (ECD). Butyltins and polybrominated diphenyl ethers (PBDEs) were extracted with organic solvents and analyzed using GC/ICPMS. All samples were analyzed within their respective hold times and quality assurance/quality control procedures included the use of blanks, duplicates, and surrogates and spikes when appropriate. All data were reviewed prior to entry into the LIMS database.

Table 2-8. Laboratory Methods and Detection Limits (wet weight) for Sediment Parameters

Parameter	Units	MDL	Method
Total Solids	%	0.005	SM2540-G
Total Organic Carbon	mg/kg	500	SM5310-G
Total Sulfide	mg/kg	10	PSEP, 1986
Total Ammonia	mg/kg	0.2	SM4500-NH3G
Metals, total, ICP	mg/kg	variable[1]	EPA 3050/6010
Mercury, total, CVAA	mg/kg	variable[1]	EPA 7471
Semivolatile (BNA[2]) Organics	µg/kg	variable[1]	SW 846 8270
Pesticides/PCBs	µg/kg	variable[1]	SW 846 8081/8082
PBDEs[3]	µg/kg	variable[1]	SW 846/ KC 2007
Organotins	µg/kg	0.3 [1]	Krone, 1988
Grain Size Distribution	%	0.1	PSEP, 1991

[1]Detection limits vary with parameter analyzed and/or total solids content. Detection limits for individual samples and analytes are provided in Appendix B.
[2] BNA indicates base/neutral/acid compounds
[3] PBDEs indicate polybrominated diphenyl ether compounds

2.4 Shellfish and Algae

The uptake of contaminants by marine organisms occurs through ingestion of food and detrital particles, water exchange at feeding and respiratory surfaces, and adsorption of chemicals onto body surfaces. These contaminants may be stored in skeletal material, concretions, and soft tissues (Kennish, 1998). Biological monitoring has been a component of the County's ambient and outfall monitoring programs for many years, as contaminants may be bioaccumulated by shellfish and algae.

In 2005 and in previous years, butter clam tissues were monitored for organic and metal contaminants. These measurements provide an indication of potential health risks to both shellfish and humans that consume them. However, organic compounds were rarely detected in shellfish tissues other than benzoic acid which is a metabolic byproduct, and thus were discontinued as part of the shellfish monitoring program. Metal concentrations continue to be monitored in shellfish tissues. Percent lipids in shellfish are also monitored as this parameter provides an indication as to the seasonal state of the organism.

Algae can absorb metals directly from seawater and tissues were monitored in 2005 and in previous years to assess metal concentrations in intertidal areas. However, the algae monitoring program was discontinued in 2006 due to sampling challenges and resultant data that provided limited use.

2.4.1 Shellfish and Algae Sampling Methods

Field Methods. The King County Environmental Services Section collected shellfish samples. Butter clams (*Saxidomus giganteus*) from each sampling station were collected by hand digging with shovels in the vicinity of siphon holes. A tarp was placed next to the digging site and excavated sediment was placed on the tarp to minimize disturbance to other organisms. The sediment was replaced after clams of sufficient size were removed. After the required number of clams was obtained, they were placed in four-liter glass jars and stored on ice until delivered to the laboratory. As organic compounds were no longer analyzed beginning in 2006, clams were placed into plastic bags and then stored on ice until laboratory delivery. A minimum of five butter clams with a shell length between 60 to 120 millimeters were collected at each station and composited into a single sample for analyses.

In 2005, algae samples were collected by the King County Environmental Services Section. Samples of attached, healthy *Ulva fenestrata* (sea lettuce) were collected and placed in 250 ml acid-washed plastic specimen cups. Discolored, dried, or free-floating algae were not collected. The sampling strategy was to collect only the most prevalent edible algae wherever possible and there was sufficient *Ulva fenestrata* at all the sampling stations to adhere to this strategy. After the required amount of algae was obtained, the containers were stored on ice until delivered to the laboratory.

Laboratory Methods. Shellfish samples were processed at the King County Environmental Laboratory in accordance with PSEP recommended protocols (PSEP, 1997). Before the clams were opened, the shells were rinsed with deionized water to remove sand and other adhering material. Each clam was measured and the lengths recorded. Tissue from each clam was removed with ceramic scalpels, composited with their liquor, and then homogenized in a sterilized blender equipped with stainless steel blades. Samples were frozen until analyzed.

Algae samples were processed at the King County Environmental Laboratory. Algae were rinsed with deionized water to remove sand and other material adhering to the plant blades. Samples from each station were processed in a blender equipped with titanium blades. Samples were then frozen until analyzed.

The King County Environmental Laboratory analyzed all shellfish and algae parameters. Methods and detection limits are provided in Table 2-9. With the exception of mercury, all metals were analyzed using ICP and/or ICP-MS depending upon detection limit requirements. Mercury was analyzed using cold-vapor atomic absorption spectroscopy. Semi-volatile organics were extracted with an organic solvent and analyzed by GC/MS. Pesticides and PCBs were extracted with organic solvents and then analyzed using a GC equipped with an ECD. Quality assurance/quality control procedures included the use of blanks, duplicates, surrogates, and spikes when appropriate. All data were reviewed prior to entry into the LIMS database.

Table 2-9. Laboratory Methods and Detection Limits for Shellfish and Algae

Parameter	Units	MDL	Method
Total Solids	%	0.005	SM2540-G
Total Lipids	%	0.1	KCEL OR 07-01-001
Metals, total, ICP	mg/kg	variable[1]	PSEP (1997)
Metals, total, ICP-MS	mg/kg	variable[1]	PSEP (1997)
Mercury, total, CVAA	mg/kg	0.004	PSEP (1997)
Semivolatile Organics	µg/kg	variable[1]	SW 846 8270
Pesticides/PCBs	µg/kg	variable[1]	SW 846 8081/8082

[1]Detection limits vary with parameter analyzed. Detection limits for individual samples and analytes are provided in Appendices C and D.

2.5 Regulatory Standards

The focus of federal water quality guidelines and state water quality standards is human health and the health of aquatic organisms. These guidelines were promulgated largely as a result of the widespread use of pesticides and other chemical compounds and the overall increase in concerns about water quality in Puget Sound. Washington State implements wildlife-based water quality standards along with human health-based standards for surface waters. When permitting point source discharges, Ecology also considers technology-based standards in the context of whether those technology-based standards will be protective of aquatic life and human health.

Current marine sediment standards are derived from the Apparent Effects Threshold (AET) method (EPA, 1988). This method compares measured chemistry values with associated biological effect data to arrive at empirically-derived chemical concentrations that predict when adverse biological effects should occur. Chemical concentrations below the standard values are predicted to have "no adverse effect". The criteria for marine sediments were developed primarily to protect benthic invertebrates, with the assumption that such criteria would also be protective of other species.

The use of bacterial indicators and water and sediment quality criteria are used to evaluate data obtained from monitoring programs. Water quality management decisions can then be based upon these findings. In addition to their use as assessment tools, environmental quality guidelines provide a basis for the development of site-specific water quality objectives for environmental contaminants. These guidelines may also be used to identify the need for source controls to reduce the input of contaminants into marine waters.

The Clean Water Act requires the States to adopt federal water quality criteria or develop their own standards which afford equal or better protection to receiving waters. Washington State has promulgated both water and sediment quality standards.

2.5.1 Washington State Standards for Marine Surface Waters

Washington State currently has numeric marine surface water quality standards for conventional pollutants (ammonia, chlorine, and cyanide) and some toxics (metals, pesticides, and PCBs) (WAC 173-201A). These standards were derived for the protection and propagation of fish, shellfish, and other aquatic life. Water quality standards for conventional pollutants and toxics in marine surface waters are provided in Table 2-10.

Marine water quality standards were revised by Ecology in late 2003. Marine standards for conventional pollutants and toxics did not change from those previously published, however, there were changes to the water use classification system. Prior to the 2003 update, Washington State surface waters were divided into five classes: AA, A, B, C, and Lake. Currently, the letter designations are no longer used and recreational water use is divided into primary contact recreation and secondary contact recreation categories. Other use designations include aquatic life (for fish and other aquatic species), shellfish harvesting, and miscellaneous uses such as wildlife habitat, commerce and navigation, boating, and aesthetics. Aquatic life use is further categorized into extraordinary quality, excellent quality, good quality, and fair quality. EPA partially approved the revisions in early 2005, which included approval of the use designations and freshwater bacteria criteria. However, the EPA did not approve selected components and in 2006 Washington State revised those standards not previously approved. EPA formally approved the 2006 Water Quality Standards in February 2008.

2.5.2 Washington State Standards for Fecal Coliforms

Washington State has marine surface water quality bacteria standards, based upon fecal coliforms. These standards were derived for the protection of human health, including protection from primary and secondary contact recreation, as well as from consumption of shellfish. As stated above, the Washington Department of Ecology (Ecology) proposed revisions to the state water quality standards in 2003. Proposed changes to the bacterial standards included the use of

Table 2-10. Washington State Marine Surface Water Quality Standards

Contaminant	Marine Water Quality Standard		Contaminant	Marine Water Quality Standard	
Trace Metals (µg/L)	**Acute**	**Chronic**	**Semivolatile Organic Compounds (µg/L)**	**Acute**	**Chronic**
Arsenic[a]	69.0	36.0	Pentachlorophenol	13.0	7.9
Cadmium [a]	42.0	9.3	Total PCBs	10.0	0.030
Chromium VI[a]	1100.0	50.0			
Copper [a]	4.8	3.1			
Lead [a]	210.0	8.1			
Mercury	1.8[a]	0.025[b]			
Nickel [a]	74.0	8.2	**Other (µg/L)**		
Selenium[a]	290	71.0	Ammonia [c] (mg/L)	0.233	0.035
Silver [a]	1.9	---	Chlorine (residual)	13.0	7.5
Zinc [a]	90.0	81.0	Cyanide (weak dissoc.)	1.0	---
Pesticides (µg/L)					
Aldrin/Dieldrin	0.71	0.0019			
Chlordane	0.09	0.004			
Chloropyrifos	0.011	0.0056			
DDT (and metabolites)	0.13	0.001			
Endosulfan	0.034	0.0087			
Endrin	0.037	0.0023			
Heptachlor	0.053	0.0036			
Lindane	0.16	---			
Toxaphene	0.21	0.0002			

[a] Criteria are based on the dissolved fraction of the metal.
[b] Criterion is based on the total recoverable fraction of the metal.
[c] Criterion is based on un-ionized ammonia.
Source: Ecology, 2006.

enterococci as the marine indicator organism rather than fecal coliforms, and that the period of averaging for obtaining the geometric mean should not exceed a 12-month period. Following a public comment period and economic feasibility analysis, Ecology determined that fecal coliforms would continue to be the marine bacterial indicator and the numeric criteria would not change from those previously published. An additional revision to the standards was to the water use classification system. The formerly Class AA marine water standard is now the primary contact recreation standard and the formerly Class A freshwater standard is now the primary contact freshwater standard. Fecal coliform counts in samples collected from both marine water and freshwater for both the ambient and outfall monitoring programs are compared with the primary contact recreation standards.

EPA proposed changes for marine surface water bacteriological criteria as part of revisions to the Water Quality Standards for Coastal and Great Lakes Recreation Waters. These national water quality standards are applicable to states without approved state water quality standards. The proposed changes incorporated the use of enterococci as an indicator of bacterial contamination in marine waters for the protection of human health. Ecology submitted data to the EPA consisting of paired samples of fecal coliform and enterococci measurements collected in Puget Sound (including King County data), the Strait of Juan de Fuca, and Pacific Ocean embayments.

Ecology requested that EPA consider keeping the State's current fecal coliform criterion since Ecology deemed the current criterion to be as protective of human health as the proposed enterococci criteria . In November 2004, EPA reviewed the data and determined that the existing Washington State fecal coliform criterion is as protective of human health as the proposed enterococci criterion and that the State was excluded from complying with the national standards proposed by EPA.

Thus, the existing fecal coliform geometric mean standard of 14 CFU/100 ml with no more than ten percent of the samples used to calculate the geometric mean exceeding 43 CFU/100 ml is the current primary contact marine water bacteria standard. The approved use designations along with the numeric criteria are provided in Table 2-11.

One part of the State fecal coliform standards is expressed as a geometric mean value. The reason for this is the high variability in fecal coliform counts, as bacteria tend to clump and adhere to particulates in water and to multiply exponentially. Transforming the data using natural logarithms can reduce this variability. This reduces the apparent differences between very high and very low numbers and simplifies plotting the data by numerically compensating for the exponential growth rate of bacteria. Results obtained from King County's monitoring programs are expressed as a moving geometric mean to facilitate comparisons with State bacteria standards. This value is obtained by taking the geometric mean value for the 12 most recent samples. As the period of averaging cannot exceed a 12-month period and samples are collected on a monthly basis, the geometric mean is calculated with 12 values. Any value reported as zero was assigned a value of one in the geomean calculation.

As well as the moving geometric mean standard, no more than 10 percent of the samples used to obtain the moving geometric mean value may exceed a defined upper limit. For the primary contact recreation (formerly Class AA) marine water standard this value is 43 colonies/100 ml and 100 colonies/100 ml for the corresponding freshwater standard. As the revisions to the bacteria standards have been approved by the regional EPA office, geometric means will be reported using the 12 most recent monthly samples.

2.5.3 Washington State Standards for Sediment

Chemicals may occur in sediment as part of the natural environment. Sediment may also become contaminated by industrial and municipal discharges, atmospheric deposition, and other non-point sources. Sediment quality guidelines provide a means of assessing sediment quality which leads to informed management decisions regarding sediments and overlying waters.

In 1991, Ecology promulgated the Sediment Management Standards (SMS) which contain numeric criteria for specific organic compounds and metals (Table 2-12). The standards specify, based on the best available knowledge, the concentrations of sediment contaminants at which no adverse effects to marine organisms are expected. These standards are derived from the Puget Sound Apparent Effects Thresholds (AETs) for selected compounds, which are based on biological testing results (EPA, 1988). Concentrations of compounds that do not exceed the SMS values are not expected to have long-term adverse effects on marine biological resources.

Table 2-11. Fecal Coliform Standards (colonies/100 ml)

Class	Moving Geometric Mean	Peak[a]
Primary Contact Recreation:		
Freshwater	100	200
Marine	14	43
Secondary Contact Recreation:		
Freshwater	200	400
Marine[b]	70	208
Extraordinary primary contact recreation		
Freshwater	50	100

[a] Not more than 10 percent of the samples used to calculate the geometric mean may exceed this value.
[b] Standard is based upon enterococci bacteria.

Source: Ecology, 2006.

The standards for metals and ionizable organic compounds are presented on a dry weight basis (the wet weight concentration divided by the decimal fraction of the total solids value), while the nonionizable organic compounds are organic carbon normalized (the dry weight concentration in µg/Kg divided by the dry weight total organic carbon content in mg/Kg multiplied by 1000).

In general, organic compounds, which make up the largest class of chemicals of concern, are associated with the organic matter contained in sediments. The nonpolar, nonionizable organic compounds (such as chlorinated hydrocarbons, aromatic hydrocarbons, and phthalates) have a tendency to adhere to organic matter in water and sediments whereas substances that form ions (such as salts, acids, bases, phenols, and metals) are soluble and therefore dissolve in water.

Organic matter in sediment is a food source for many benthic organisms (organisms that live on or near bottom sediments). Too little organic matter will not support these organisms and too much will reduce the number and/or diversity of organisms due to natural toxic effects associated with enhanced microbial activity. The organic carbon content of sediments has been shown to be related to the bioavailability and toxicity of some organic compounds to aquatic organisms (Di Toro et al., 1991). Grain size affects the amount of organic carbon contained in sediments with predominantly silt/clay sediments usually containing higher amounts of organic carbon than sandy sediments due to fine-grained sediments having a greater amount of surface area for adsorption of organic matter.

The presence of contaminants in sediment does not necessarily indicate that the sediment is toxic to marine organisms. An important factor in determining toxicity is how much of a compound is available for uptake directly into an organism or accumulated through the food chain. The toxicity of organic compounds in sediments appears to be more closely correlated to the concentration of organic carbon in the sediments rather than the dry weight concentration. Thus, a more accurate measure of contaminant toxicity is obtained if the data are “normalized” for the

Table 2-12. Washington State Sediment Standards

Contaminant	Sediment Quality Standard	Lowest Apparent Effects Threshold
Metals	**mg/kg dry weight**	
Arsenic	57	
Cadmium	5.1	
Chromium	260	
Copper	390	
Lead	450	
Mercury	0.41	
Silver	6.1	
Zinc	410	
Nonionizable Organic Compounds	**mg/kg organic carbon**	**µg/kg dry weight**
Total LPAHs [a]	370	5200
Naphthalene	99	2100
Acenapthylene	66	1300
Acenapthene	16	500
Fluorene	23	540
Phenanthrene	100	1500
Anthracene	220	960
2-Methylnaphthalene	38	670
Total HPAHs [b]	960	12000
Fluoranthene	160	1700
Pyrene	1000	2600
Benzo(*a*)anthracene	110	1300
Chrysene	110	1400
Total Benzofluoranthenes	230	3200
Benzo(*a)* pyrene	99	1600
Indeno(1,2,3-*c,d*)pyrene	34	600
Dibenzo(*a,h*)anthracene	12	230
Benzo(*g,h,i*)perylene	31	670

Contaminant	Sediment Quality Standard	Lowest Apparent Effects Threshold
Nonionizable Organic Compounds	**mg/kg organic carbon**	**µg/kg dry weight**
1,2-Dichlorobenzene	2.3	35
1,4-Dichlorobenzene	3.1	110
1,2,4-Trichlorobenzene	0.81	31
Hexachlorobenzene	0.38	22
Dimethyl phthalate	53	71
Diethyl phthalate	61	200
Di-n-butyl phthalate	220	1400
Butyl benzyl phthalate	4.9	63
Bis (2-ethylhexyl) phthalate	47	1300
Di-n-octyl phthalate	58	6200
Dibenzofuran	15	540
Hexachlorobutadiene	3.9	11
N-Nitrosodiphenylamine	11	28
Total PCBs	12	130
Ionizable Organic Compounds	**mg/kg dry weight**	
Phenol	0.42	
2-Methylphenol	0.063	
4-Methylphenol	0.67	
2,4-Dimethylphenol	0.029	
Pentachlorophenol	0.36	
Benzyl alcohol	0.057	
Benzoic acid	0.65	

[a] Represents the sum of the following low molecular weight PAHs: Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, and Anthracene.

[b] Represents the sum of the following high molecular weight PAHs: Fluoranthene, Pyrene, Chrysene, Benz(*a*)anthracene, Benzo(*a*)pyrene, total Benzofluoranthenes, Indeno(1,2,3-*c,d*)pyrene, Dibenzo(*a,h*)anthracene, and Benzo(*g,h,i*)perylene.

Source: Ecology, 1995

total organic carbon (TOC) content. For this reason, the State standards for nonionizable organics are based upon concentrations that have been TOC normalized (Michelson, 1992). However, when TOC values are very low (e.g. <0.2 %) it is not appropriate to normalize contaminant values as even background levels may exceed regulatory standards. When the TOC content is less than 0.5%, dry weight values are more appropriate to use than organic carbon normalized values (Michelson, 1992). These dry weight sediment concentrations are then compared to Puget Sound *Lowest Apparent Effects Thresholds* (LAETs), which are effects-based values, deemed to be protective of benthic infauna (EPA, 1988).

2.5.4 Standards for Biota

In addition to contaminants found in water and sediment, several contaminants have the potential to accumulate in the tissues of aquatic biota, such as fish and shellfish. Bioaccumulation in biota may affect not only the species directly accumulating the contaminants, but humans and other species that consume the affected organisms. Numerical tissue-residue guidelines provide a basis for assessing the hazards that tissue-laden contaminants pose to human health and wildlife, and therefore, a basis for regulating contaminant inputs into the environment. Ecology does not currently have tissue-residue standards, however, heavy metal concentrations in shellfish samples were compared with the Food and Drug Administration (FDA) guidelines listed in Table 2-13 that were established for the protection of human health.

Table 2-13. FDA Levels of Concern in Shellfish Tissues

	mg/Kg wet weight
	Level of Concern
Arsenic	55
Cadmium	3
Chromium	11
Lead	0.8
Nickel	80
	Action Level
Mercury	1.0

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